UNCLASSIFIED

AD 432259

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

64-10

U.S. Forest Service Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE • FOREST SERVICE • FOREST PRODUCTS LABORATORY • MADISON WIS

In Cooperation with the University of Wisconsin

SHORT-COLUMN COMPRESSIVE STRENGTH OF SANDWICH CONSTRUCTIONS AS AFFECTED BY SIZE OF CELLS OF HONEYCOMB CORE MATERIALS

JANUARY 1964

FPL-026

This Report is One of a Series Issued in Cooperation with the MIL-HDBK-23 WORKING GROUP ON COMPOSITE CONSTRUCTION FOR FLIGHT VEHICLES of the Departments of the AIR FORCE, NAVY, and COMMERCE

SHORT-COLUMN COMPRESSIVE STRENGTH OF SANDWICH CONSTRUCTIONS AS AFFECTED BY SIZE OF CELLS OF HONEYCOMB CORE MATERIALS[1,2]

By

C. B. NORRIS, Engineer

Forest Products Laboratory,[3] Forest Service
U.S. Department of Agriculture

Summary

To determine the effect of honeycomb core cell size on edgewise compression of sandwich constructions, sandwich specimens were evaluated that had aluminum facings of various thicknesses and a solid core of Sitka spruce in which a cell of a honeycomb core material was simulated by a round hole. A few tests involving honeycomb cores were made, and results of these were found to agree with those of the other tests for the stress at the start of dimpling of the facings. The maximum stress in the facings of the honeycomb core specimens was lower at failure than for the specimens with wood cores. At failure, the honeycomb core sandwich specimens had a wrinkle-type failure in the facing, with some failure in the bond between the facing and core.

An empirical formula was obtained that can be used to estimate the critical stress at which dimpling of the facing over the cell voids begins.

---

[1] Revision by E. W. Kuenzi and G. H. Stevens of a report by Norris and W. J. Kommers issued under the same title as Forest Products Laboratory Report No. 1817, August 1950.

[2] This progress report is one of a series (ANC-23, Item 58-3) prepared and distributed by the Forest Products Laboratory under U.S. Navy, Bureau of Naval Weapons Order No. 19-64-8004 WEPS and U.S. Air Force Contract No. 33(657)63-358. Results here reported are preliminary [illegible]

Introduction

The edgewise compressive strength of sandwich constructions with honeycomb cores may be limited by the instability of the facings where they span the voids between the cell walls of the core material. Each small section of facing acts as a plate of roughly circular shape, subjected to edgewise compression. The edgewise load on the sandwich construction may be limited by the dimpling (buckling) of these small plates. The dimpling stress is influenced by the thickness and modulus of elasticity of the facing, the edge conditions of the plate, and the cell size of the honeycomb material.

The work reported is an experimental study of these effects. Because of the difficulty of predetermining just where the facings of a sandwich with a honeycomb core will buckle first, most of the experiments were made on sandwich constructions having a solid core of end-grain Sitka spruce, with a single circular hole drilled in them. A number of tests were made on sandwich constructions having honeycomb cores, but the location of the first buckle was guessed correctly in only three tests. The results at the beginning of buckling of those three tests, however, agreed well with those obtained from the tests involving the other core materials.

The results of tests in which failures were due to causes other than the instability of the facings over the core void are not included in this report.

Materials

The facings of the specimens tested were all 24 ST clad aluminum in nominal thicknesses of either 0.012, 0.020, 0.032, or 0.064 inch, conforming to Air Force-Navy Aeronautical Specification AN-A-13, January 14, 1943.

The core materials combined with the aluminum facings were end-grain Sitka spruce or resin-impregnated paper honeycomb.

The Sitka spruce was clear, straight-grained material of aircraft quality.

The paper-honeycomb core material[4] was made at the Forest Products Laboratory and had a nominal 3/8-inch, hexagonally shaped cell. This material was formed by the expansion method in the following steps: (1) Flat sheets of 10-inch-wide, 40-pound kraft paper

---

[4] ... in cooperation with the National Advisory Committee

(weight per 3,000 square feet) were pretreated with about 10 percent of a high-temperature-setting phenolic resin, thinned with alcohol and water; (2) the pretreated sheets were striped on one side with phenolic glue lines approximately 3/16 inch wide and spaced approximately 3/4 inch apart; (3) the sheets were laid up in a pack, with the stripes in adjacent sheets staggered 3/8 inch, and cured in a press; (4) the pack was expanded like an accordion to produce the nominal 3/8-inch cells; (5) the material was impregnated with a phenolic resin and cured in the expanded form.

Preparation of Specimens

Facings

The aluminum sheet facing material was cut 2-1/2 inches wide and 3-1/2 inches long and then cleaned and etched in a sulfuric acid bath. The prepared sheets were then sprayed, allowing a 1/2-hour drying period between coats, with six coats of a high-temperature-setting mixture of a thermosetting resin and synthetic rubber to a total film thickness of approximately 0.003 inch. They were then air dried 16 hours and then cured at 325° F. for 1/2 hour.

Cores

The two materials used for cores were prepared by the following procedures. Individual core blanks were cut from large blocks to 1/2 inch in thickness (grain direction of wood cores was oriented parallel to the thickness dimension) by 2-1/2 inches in width by 3-1/2 inches in length. The blanks were then drilled at the center to make one hole of a predetermined size. The thickness dimension, being a critical factor if not uniform, was not allowed to vary more than 0.002 inch over the cross section of each specimen. The honeycomb core blanks were made in the same way, except that no additional holes were drilled.

Sandwich

The facings and core materials were then assembled into separate specimens, employing a high-temperature-setting, acid-catalyzed (20 percent) phenolic resin for the bond between the prepared facings and the cores. This resin was a room-temperature-setting adhesive, and the wood specimens were allowed to cure in the press under 100 pounds of pressure per square inch for 16 hours. The honeycomb core specimens were made in a similar manner, except that the pressing was made at 25 pounds per square inch.

After removal from the press, the specimens were cut with a circular saw to 2 inches in width by 3-1/16 inches in length. A final milling cut was taken on the longer dimension to insure square and parallel ends in contact with the loading heads of the testing machine. The final length was 3 inches.

All specimens were conditioned to approximate constant weight in a room maintained at 65 percent relative humidity and 75° F. Electric resistance strain gages were attached to each facing of each specimen with a commercial adhesive and allowed to cure for 48 hours.

Test Methods

Figure 1 indicates the position of a typical specimen in the testing machine. The wires to the strain gages were attached to a strain indicator calibrated to indicate the strain of the facings in microinches. Two dial gages (0.001 inch least reading) were placed at right angles to each facing, one over the center of the hole in the core and one near the edge of the specimen. All the tests were made in the same hydraulic testing machine. Deformations and deflections as indicated by the strain gages and dial gages were recorded for equal increments of load until the specimen failed.

The specimens were laterally supported adjacent to their ends and as a preliminary adjustment, each specimen was lightly loaded to determine if there might be slight eccentricity of loading, as indicated by unequal strains; if so, the position of the specimen was adjusted until its facings were equally loaded, as indicated by equal strain in both facings. The dial gages at the center of each face indicated the lateral deformation of the unsupported plate over the hole in the core material. The dials at the edges of the specimen were used to determine if there was any twisting or shifting of the specimen within the machine during the loading period that might influence the lateral deflection readings. From these readings, a load-deflection curve was plotted. Curves similar to those exhibited by flat plates subjected to edgewise compression were obtained. Figure 2 is the type of curve obtained when the load was plotted against the facing lateral deflection for a specimen with aluminum facing and Sitka spruce core with a 1/2-inch hole. The load at which buckling of the facing over the hole began (dimpling) was picked at the point in the curve where the deflection started to increase.

Since it was necessary to know the stress-strain characteristics of the facing materials over the full range of the strains encountered in the sandwich tests, tests were required of coupons of the aluminum sheets in edgewise compression. The thin sheet material was laterally supported by thin spring steel fingers to prevent buckling during the test. This

support did not measurably affect the edgewise compressive deformation. A Marten's mirror compressometer, having a 1-inch gage length, was attached to the central portions of the edges of the specimen. This method of testing sheet material was originally devised for the testing of thin plywood specimens and is more fully described in Forest Products Laboratory Report No. 1316-D[5] or Standard D 805 of the American Society for Testing and Materials. These tests are summarized in the stress-strain curves of figure 3 and in figure 4 where the parameter $F\lambda/E'$ is plotted for various values of F. Values of the tangent modulus of elasticity, E', were determined from the slope of the stress-strain curve at various values of F. The value of $\lambda = 1 - \mu^2$ was assumed constant for Poisson's ratio, $\mu = 0.3$.

A few tests were made to determine the properties of the Sitka spruce core material in compression. Compression tests on 2-inch-square and 6-inch-long clear specimens were made in accordance with procedures presented in American Society for Testing and Materials Test Method D 143-52. The modulus of elasticity in compression perpendicular to the grain direction was found to be 137,000 pounds per square inch.

Presentation of Data

The results of the individual tests are given in table 1. From one to six tests were made on duplicate specimens. In table 1, the load and facing stress at which dimpling (buckling) of the facing over the simulated cell void begins and the maximum load at failure are presented.

The experimental facing stress for a sandwich in edgewise compression is normally computed by dividing the edge load by the facing area, thus neglecting any load carried by the usual sandwich core of low stiffness. Cores of Sitka spruce, however, have elastic moduli that are not negligible; hence the load supported by the core must be considered. To correct for the load carried by the core, a formula was derived for computing the facing stresses in the elastic range. Here the assumptions were made that the strains in facings and core are equal, and that core width is reduced by the diameter of the hole. This formula is:

$$F = \frac{P}{2tb + \frac{E_c}{E}(b - s)\, t_c} \tag{1}$$

---

[5]Norris, C. B., and Voss, A. W. Buckling of Flat Plywood Plates in Compression, Shear, or Combined ...

where $\underline{F}$ is facing stress, $\underline{P}$ is specimen edge load, $\underline{t}$ is facing thickness, $\underline{b}$ is specimen width, $\underline{s}$ is diameter of core cell hole, $\underline{t_c}$ is core thickness, $\underline{E}$ is facing elastic modulus, and $\underline{E_c}$ is core elastic modulus.

Formula (1) with E_c = 137,000 pounds per square inch and E = 10,000,000 pounds per square inch was used to compute experimental facing stresses at beginning dimpling, given in table 1, provided the computed stress was below 27,000 pounds per square inch (proportional limit stress). At stresses greater than 27,000 the facing stress was determined by entering the stress-strain curves given in figure 3 with the strain reading given by the electric strain gages attached to the facings at the dimpling load.

Maximum specimen loads are also given in table 1 and serve to indicate that loads from a few percent greater to several times greater than beginning dimpling can be withstood before failure. Analysis of maximum loads was not attempted because failures of facings over a solid core with a hole may not apply to realistic constructions with honeycomb cores. The observed failures consisted largely of a growth of the dimple toward the specimen edges, with resultant bond failure between facing and core, thus tending to resemble a large facing wrinkle.

Analysis of Data

The stress at which buckling of a flat plate of isotropic material under edge load occurs is well defined in the literature as given by the formula

$$F = K \frac{E'}{\lambda} \left(\frac{t}{s}\right)^2 \qquad (2)$$

where $\underline{E'}$ is the effective elastic modulus of the plate material; $\lambda = 1 - \mu^2$, with $\underline{\mu}$ as Poisson's ratio of the plate material; $\underline{t}$ is the plate thickness; $\underline{s}$ is the plate size; and $\underline{K}$ is a buckling coefficient dependent upon plate shape and edge support.

The coefficient, $\underline{K}$, for a plate of the shape of a core cell and for the type of edge support on this plate is not known. A reasonable value of $\underline{K}$ can be determined from the experimental data for dimpling stresses of facings of various thicknesses over core cells of various sizes. Values of $\underline{F\lambda/E'}$ were determined from the experimental dimpling stress and the elastic modulus for stresses below proportional limit values and for tangent modulus of elasticity at the experimental stress for stresses above proportional limit values. The latter determination of $\underline{F\lambda/E'}$ values was made by entering the curves of figure 4 with experimental stress values. The resultant values of $F\lambda/E'$ are given in

scatter in the data shown in figure 5, the trend is fairly well described by t/s to the second power (slope of 2:1 of a straight line on a logarithmic graph) and a buckling coefficient of 2. Sixteen of 17 data points fall above the line in the elastic range and half the data fall above the line beyond the elastic range. The theoretical line for a simply supported square plate which has a buckling coefficient of 4 is also shown in figure 5.

Conclusions

An approximation to the facing stress at which dimpling of the facings of a sandwich with a core of open cells can be made with the formula

$$F = 2\frac{E'}{\lambda}\left(\frac{t}{s}\right)^2$$

Table 1.--Data obtained from sandwich edgewise compression specimens

Sandwich thickness	Facing thickness t	Core cell size, s	t/s	Load per specimen[1] Dimpling	Load per specimen[1] Maximum	Facing stress (F) at beginning dimpling	Fλ/E' at dimpling[2]
In.	In.	In.		Lb.	Lb.	P.s.i.	
			SITKA SPRUCE CORE				
0.532	0.012	1/8	0.096	2,800	3,560	47,000	0.0245
.531	.012	3/8	.032	1,400	2,660	25,000	.00228
.532	.012	3/8	.032	1,800	2,920	28,000	.00254
.534	.012	1/2	.024	1,200	2,240	20,500	.00186
.534	.012	1/2	.024	1,000	2,260	17,000	.00154
.537	.012	1/2	.024	1,400	2,220	24,000	.00218
.535	.012	1/2	.024	1,400	2,380	24,300	.00221
.534	.012	1/2	.024	1,300	2,380	22,200	.00202
.529	.012	1/2	.024	1,600	2,520	27,400	.00249
.532	.012	5/8	.019	1,000	2,020	17,300	.00157
.530	.012	5/8	.019	1,100	2,040	19,100	.00174
.528	.012	3/4	.016	800	2,020	14,100	.00128
.522	.012	1	.012	560	1,760	10,200	.00093
.526	.012	1	.012	800	1,520	14,600	.00133
.548	.020	3/8	.053	3,600	4,520	36,000	.0076
.547	.020	3/4	.027	1,600	3,520	18,000	.00164
.548	.020	3/4	.027	1,600	3,460	18,000	.00164
.554	.020	3/4	.027	2,000	3,420	22,500	.00204
.572	.032	1/4	.128	6,300	8,220	45,000	.0235
.569	.032	1/4	.128	6,000	8,440	43,000	.0200
.570	.032	3/8	.085	4,800	7,540	34,000	.0060
.568	.032	3/8	.085	5,400	7,620	38,500	.0107
.574	.032	5/8	.051	4,800	5,620	32,500	.0050
.572	.032	5/8	.051	4,800	6,500	32,500	.0050
.572	.032	3/4	.043	4,800	6,120	31,500	.0044
.572	.032	3/4	.043	5,200	6,140	35,500	.0073
.572	.032	3/4	.043	4,800	5,960	33,000	.0053
.571	.032	7/8	.037	4,000	5,620	28,500	.0032
.572	.032	7/8	.037	4,000	5,540	28,500	.0032
.571	.032	7/8	.037	4,000	5,780	28,000	.0030

Table 1.--Data obtained from sandwich edgewise compression specimens--Cont'd.

Sandwich thickness	Facing thickness t	Core cell size, s	t/s	Load per specimen[1]: Dimpling	Load per specimen[1]: Maximum	Facing stress (F) at beginning dimpling	$F\lambda/E'$ at dimpling[2]
In.	In.	In.		Lb.	Lb.	P.s.i.	
			SITKA SPRUCE CORE				
0.571	0.032	1	0.032	3,200	5,500	23,700	0.00216
.571	.032	1	.032	3,600	5,400	28,000	.0030
			PAPER HONEYCOMB CORE				
.529	.012	3/8	.032	600	1,600	12,500	.00114
.526	.012	3/8	.032	1,350	1,560	28,100	.00255
.526	.012	3/8	.032	1,350	1,540	28,100	.00255

[1] Specimens of 2-inch width.

[2] E' is tangent elastic modulus at facing stress and $\lambda = 1 - \mu^2$ where $\mu = 0.3$.

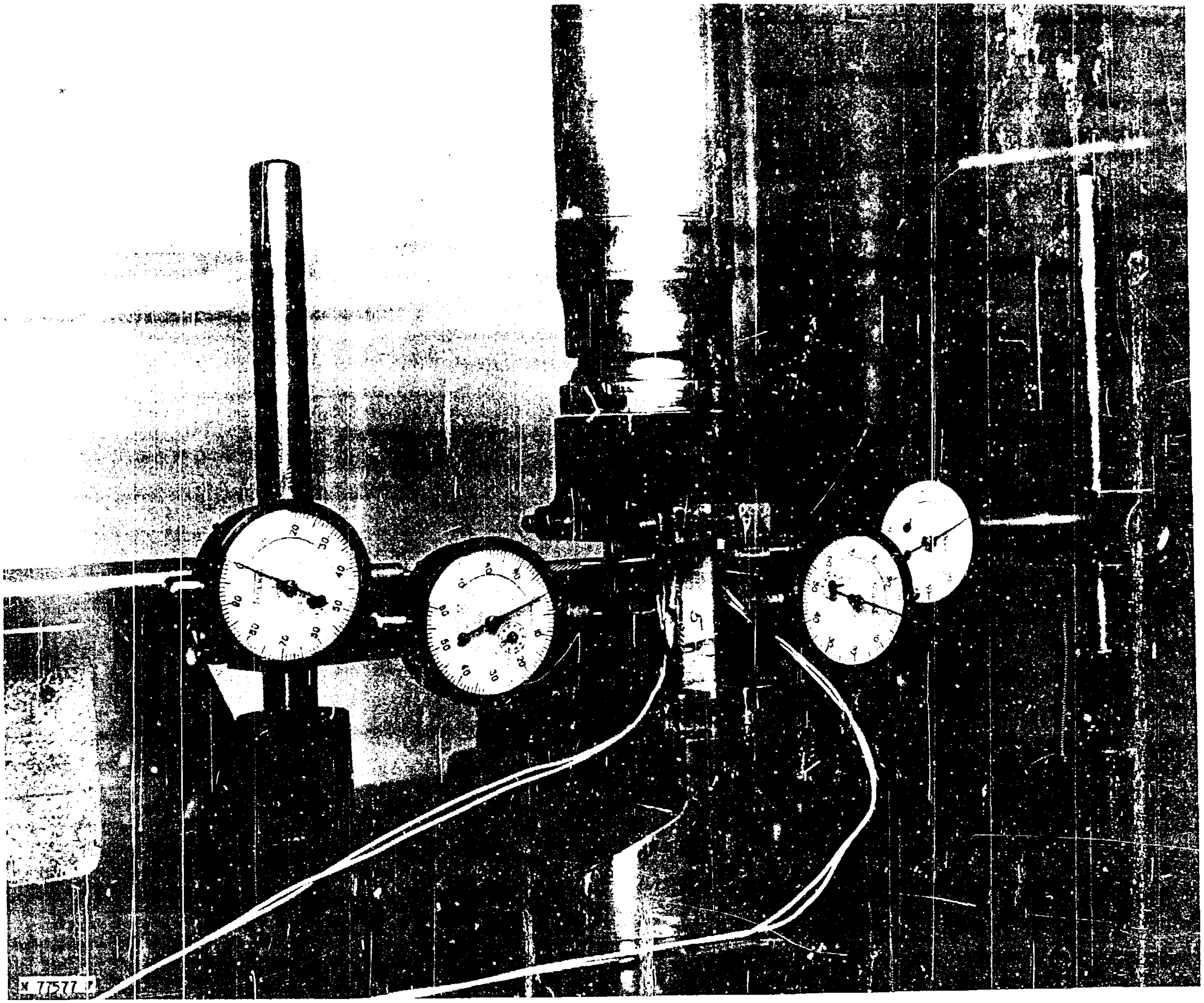

Figure 1.--Edgewise compression test apparatus, showing the sandwich specimen placed for test, the position of the loading head, the end supports, and the dial and electric strain gages.

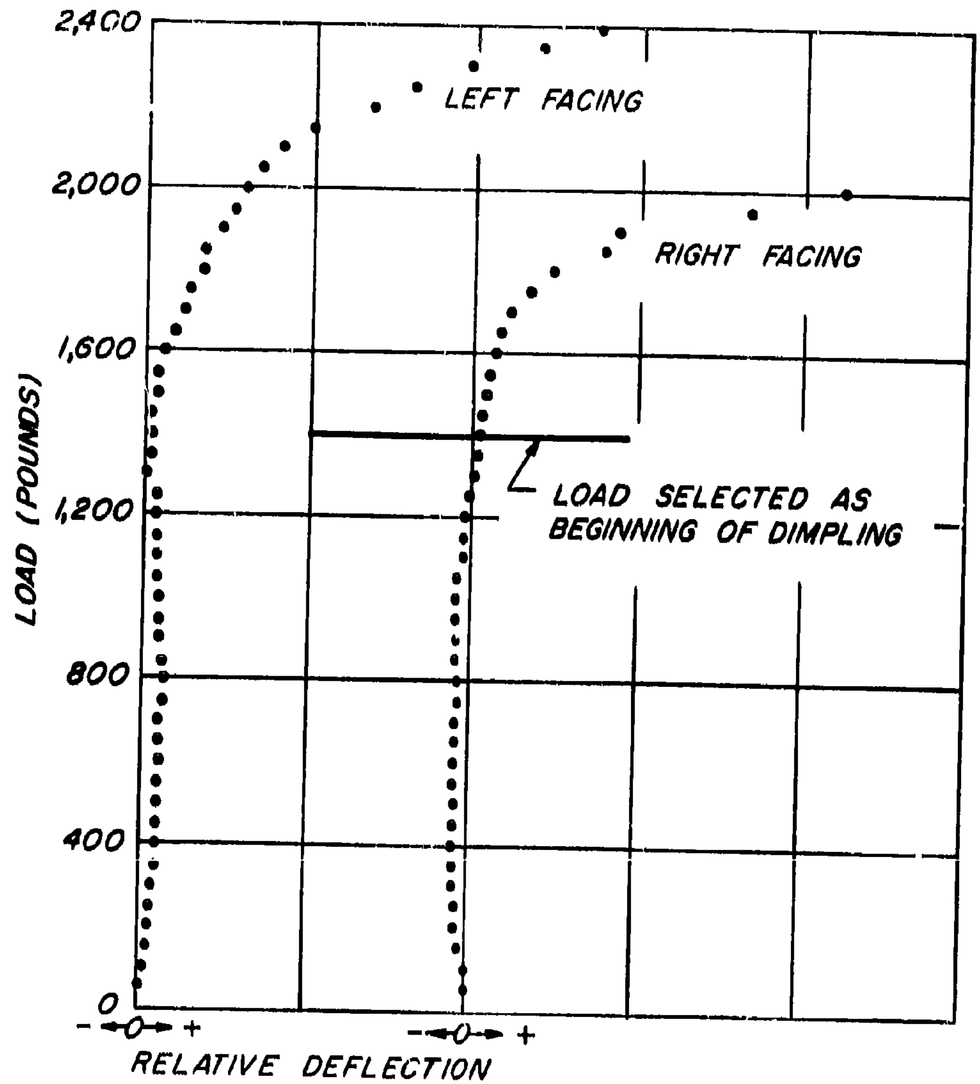

Figure 2.--Typical load deflection curves showing dimpling of 0.012 inch aluminum facing over a 1/2-inch diameter hole in sitka spruce core.

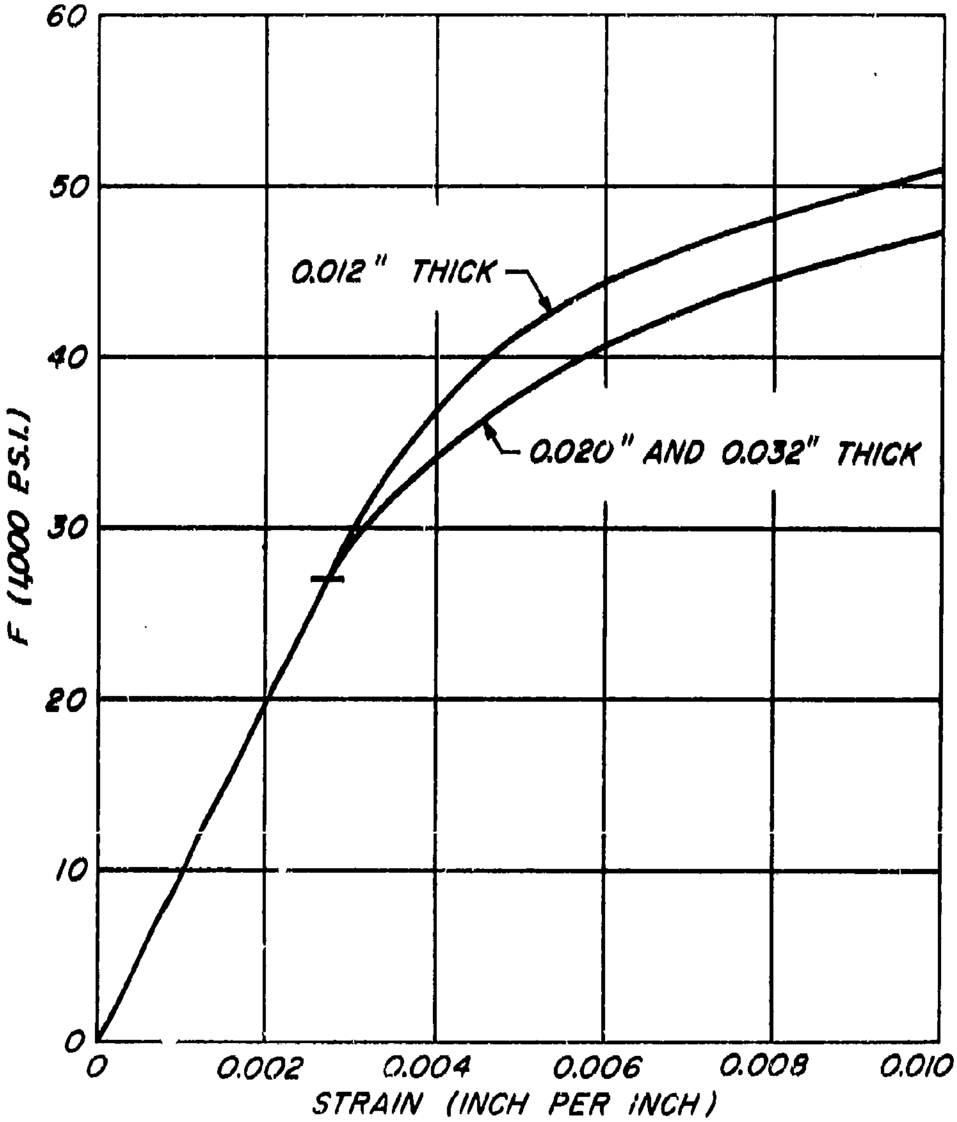

Figure 3.--Stress-strain curves for 24 ST clad aluminum facings.

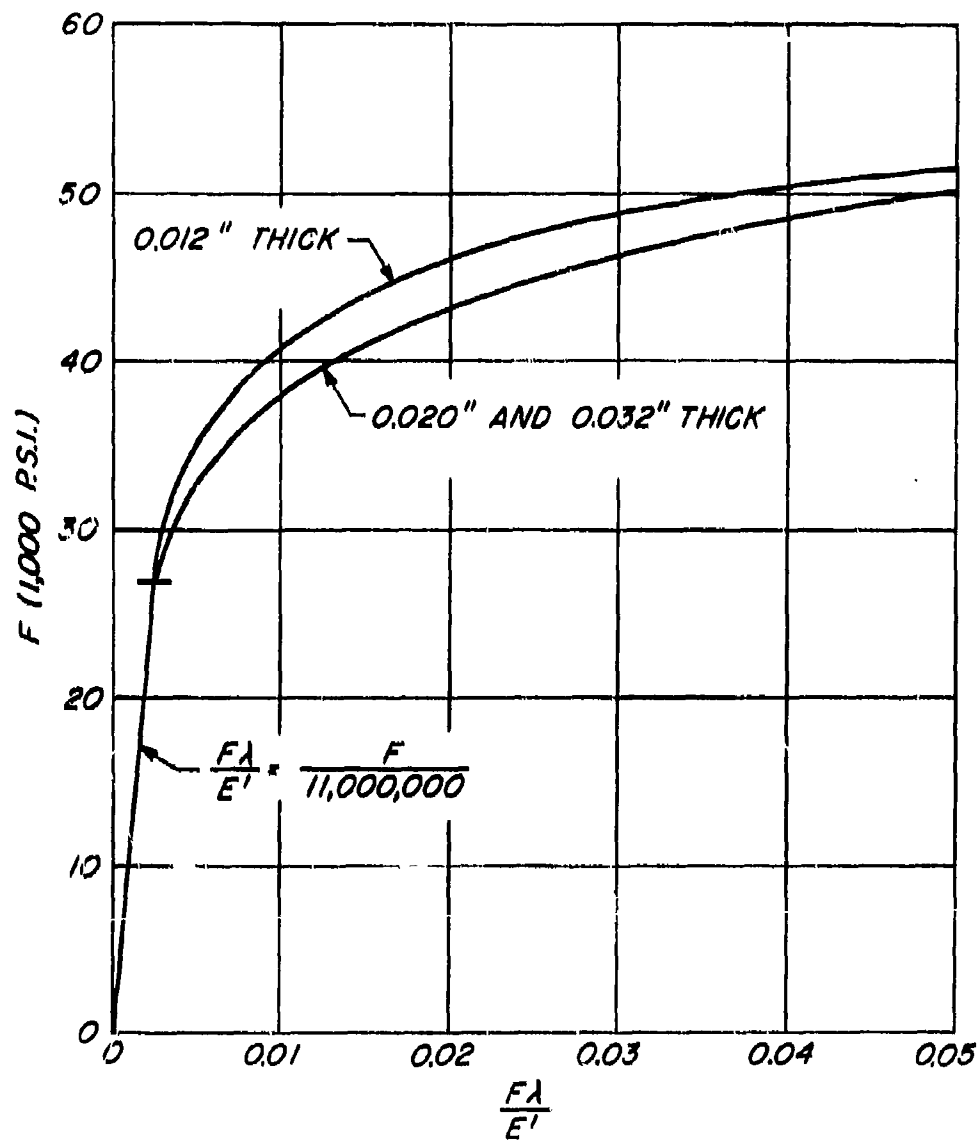

Figure 4.--Facing stress of 24 ST clad aluminum as a function of parameter $\frac{F\lambda}{E'}$.

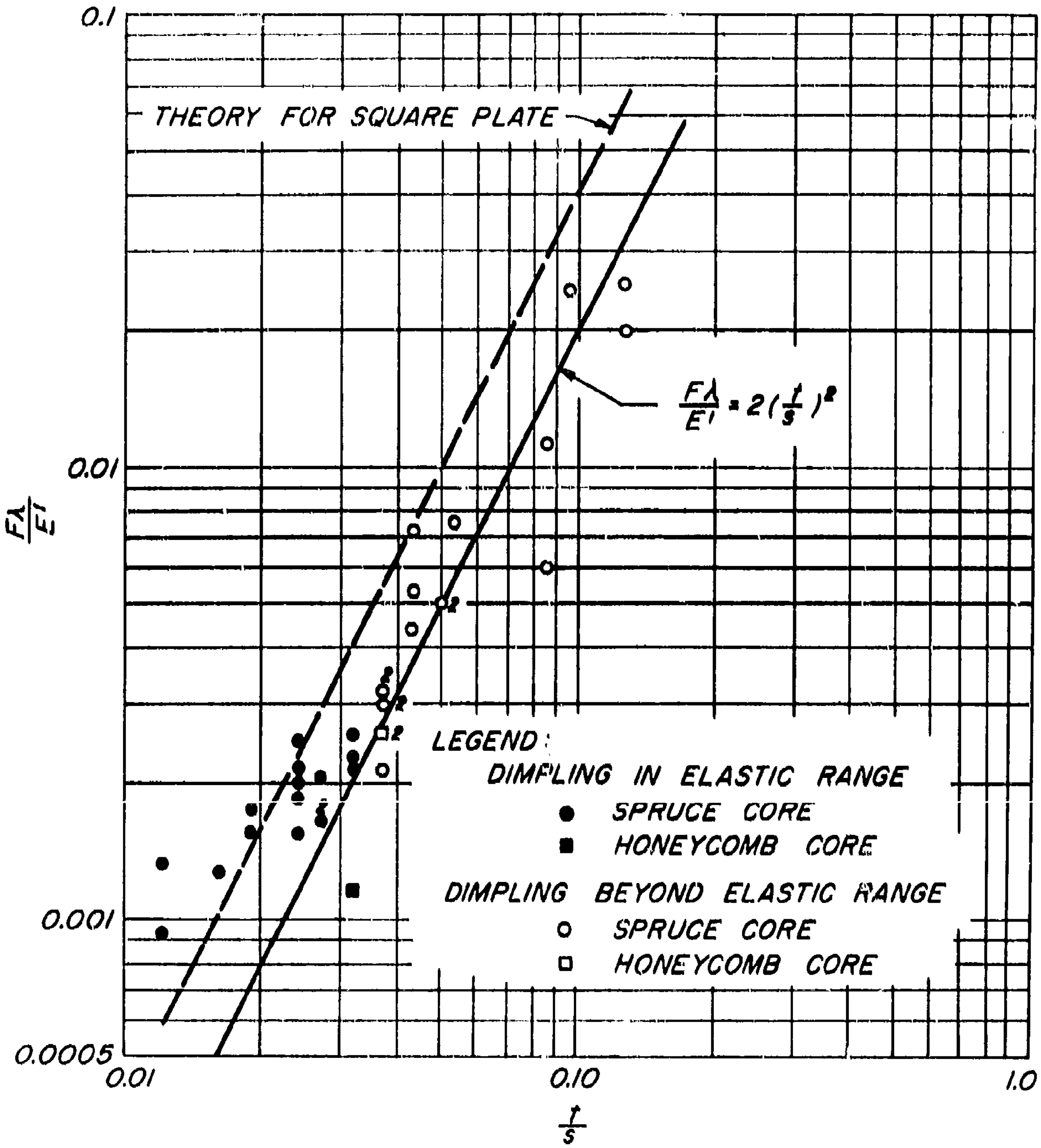

Figure 5. -- Variation of dimpling and maximum stress with t/s

U.S. Forest Products Laboratory.
Short-column compressive strength of sandwich constructions as affected by size of cells of honeycomb core materials, by C. B. Norris. Madison, Wis., The ... Laboratory, 1964.
7 p., illus. (U.S. FS res. note FPL-026)

To determine the effect of honeycomb core cell size on edgewise compression of sandwich constructions, sandwich specimens were evaluated that had aluminum facings of various thicknesses and a solid core of Sitka spruce in which a cell of a honeycomb core material was simulated by a round hole. A few
(contd) over

U.S. Forest Products Laboratory.
Short-column compressive strength of sandwich constructions as affected by size of cells of honeycomb core materials, by C. B. Norris. Madison, Wis., The ... Laboratory, 1964.
7 p., illus. (U.S. FS res. note FPL-026)

To determine the effect of honeycomb core cell size on edgewise compression of sandwich constructions, sandwich specimens were evaluated that had aluminum facings of various thicknesses and a solid core of Sitka spruce in which a cell of a honeycomb core material was simulated by a round hole. A few
(contd) over

U.S. Forest Products Laboratory.
Short-column compressive strength of sandwich constructions as affected by size of cells of honeycomb core materials, by C. B. Norris. Madison, Wis., The ... Laboratory, 1964.
7 p., illus. (U.S. FS res. note FPL-026)

To determine the effect of honeycomb core cell size on edgewise compression of sandwich constructions, sandwich specimens were evaluated that had aluminum facings of various thicknesses and a solid core of Sitka spruce in which a cell of a honeycomb core material was simulated by a round hole. A few
(contd) over

U.S. Forest Products Laboratory.
Short-column compressive strength of sandwich constructions as affected by size of cells of honeycomb core materials, by C. B. Norris. Madison, Wis., The ... Laboratory, 1964.
7 p., illus. (U.S. FS res. note FPL-026)

To determine the effect of honeycomb core cell size on edgewise compression of sandwich constructions, sandwich specimens were evaluated that had aluminum facings of various thicknesses and a solid core of Sitka spruce in which a cell of a honeycomb core material was simulated by a round hole. A few
(contd) over

tests involving honeycomb cores were made, and results of these were found to agree with those of the other tests for the stress at the start of dimpling of the facings. The maximum stress in the facings of the honeycomb core specimens was lower at failure than for the specimens with wood cores. At failure, the honeycomb core sandwich specimens had a wrinkle-type failure in the facing, with some failure in the bond between the facing and core. An empirical formula was obtained that can be used to estimate the critical stress at which dimpling of the facing over the cell voids begins.

tests involving honeycomb cores were made, and results of these were found to agree with those of the other tests for the stress at the start of dimpling of the facings. The maximum stress in the facings of the honeycomb core specimens was lower at failure than for the specimens with wood cores. At failure, the honeycomb core sandwich specimens had a wrinkle-type failure in the facing, with some failure in the bond between the facing and core. An empirical formula was obtained that can be used to estimate the critical stress at which dimpling of the facing over the cell voids begins.

tests involving honeycomb cores were made, and results of these were found to agree with those of the other tests for the stress at the start of dimpling of the facings. The maximum stress in the facings of the honeycomb core specimens was lower at failure than for the specimens with wood cores. At failure, the honeycomb core sandwich specimens had a wrinkle-type failure in the facing, with some failure in the bond between the facing and core. An empirical formula was obtained that can be used to estimate the critical stress at which dimpling of the facing over the cell voids begins.

tests involving honeycomb cores were made, and results of these were found to agree with those of the other tests for the stress at the start of dimpling of the facings. The maximum stress in the facings of the honeycomb core specimens was lower at failure than for the specimens with wood cores. At failure, the honeycomb core sandwich specimens had a wrinkle-type failure in the facing, with some failure in the bond between the facing and core. An empirical formula was obtained that can be used to estimate the critical stress at which dimpling of the facing over the cell voids begins.